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Effects of Uneven Interfacial Strength on Damage Evolution in Composites

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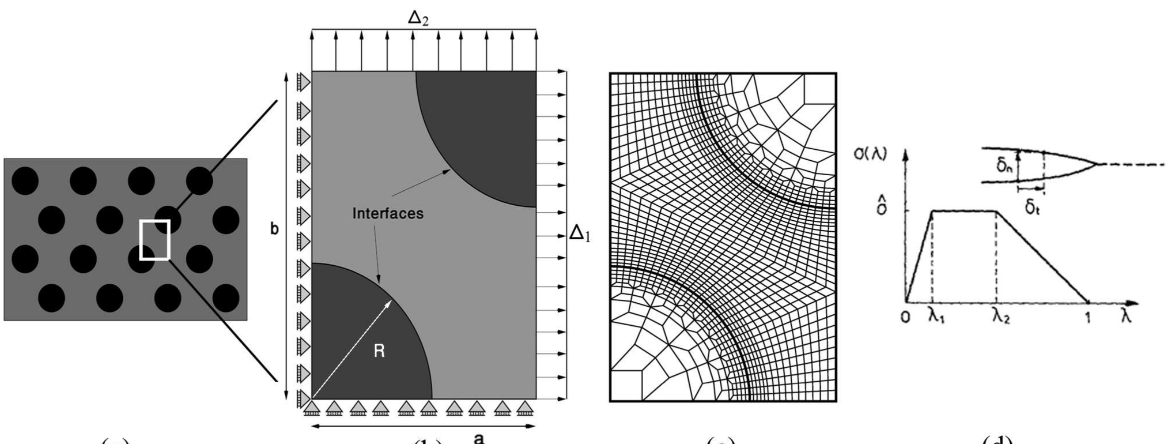
ABSTRACT

The micro-scale interfacial effects in fiber-reinforced composites are studied using generalized plane strain by means of the finite element analysis. Assuming a periodic distribution of fibers in the matrix (see Fig. 1(a)), a unit cell is chosen including two quarter-circular fibers as shown in Fig. 1(b). By using this unit cell approach the composite material is modeled more realistically as the possibility of having different fiber-matrix strength exists. In the present investigation three different cases are considered: I) Two perfectly bonded interfaces. II) One debonding interface and one perfectly bonded interface. III) Two debonding interfaces of uneven strength. In this work, the fibers behave purely elastic while the matrix is considered as isotropic with an either purely elastic or elasto-plastic behavior. To model the fracture of the fiber-matrix interfaces, the trapezoidal cohesive zone model [3] is used (see Fig. 1(d)). The normal and tangential tractions acting on the interfaces are defined in eq. (1), where λ is a non-dimensional parameter describing the separation. Here, δ_n and δ_t are the normal and tangential characteristic cohesive lengths, respectively, and, u_n and u_t are the normal and tangential separation of the interface, respectively, with T_n and T_n denoting the corresponding normal and tangential tractions in the interface. In Fig. 1(d), the area under $\sigma(\lambda)$ represents the fracture work.

$$T_n = \frac{\sigma(\lambda)}{\lambda}\frac{u_n}{\delta_n}, \quad T_t = \frac{\sigma(\lambda)}{\lambda}\frac{\delta_n}{\delta_t}\frac{u_t}{\delta_t} \quad \text{where} \quad \lambda = \sqrt{\left(\frac{u_n}{\delta_n}\right)^2 + \left(\frac{u_t}{\delta_t}\right)^2} \tag{1}$$



(a) (b) (c) (d)

Figure 1: (a) The fiber distribution in the matrix of the composite. (b) The unit cell including two quartercircular fibers. (c) A finite element mesh used in the numerical computations. (d) Traction-separation law used to characterize interface separation [3].

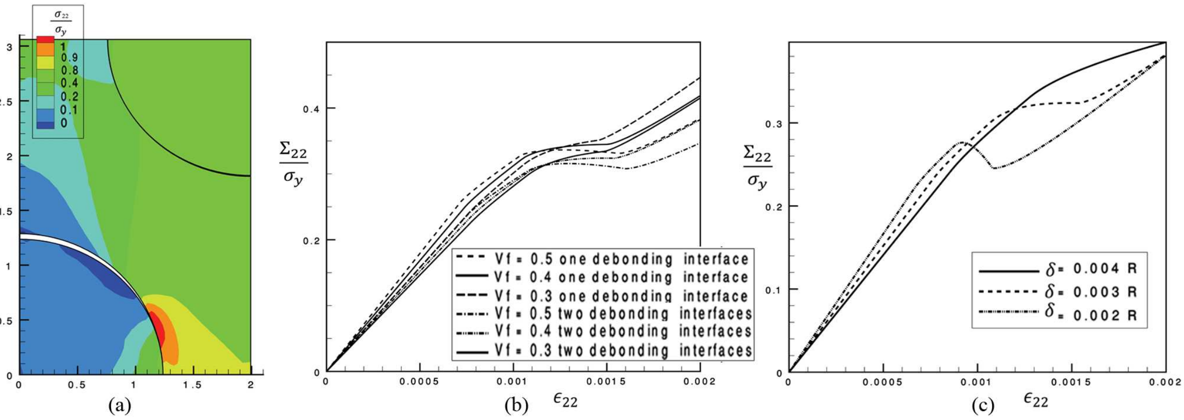


Figure 2: Results for the case II with $\frac{b}{a} = 1.5$ and the maximum cohesive stress, $\sigma_{max} = 0.004E_m$. For the matrix, $\nu_m = 0.3$ and for the fibers, $E_f = 5.7E_m$ and $\nu_f = 0.17$. (a) Contour plot of $\frac{\sigma_{22}}{\sigma_{max}}$ for uniaxial tension in the x_2 direction with $\delta_n = \delta_t = 0.003R$ and $V_f = 0.4$. (b) Overall response curves are shown for by different fiber volume fraction with $\delta_n = \delta_t = 0.003R$ and (c) different cohesive zone model parameters with $V_f = 0.4$.

For the numerical implementation, the incremental form of the principle of virtual work is

$$\Delta t \int_V \dot{\sigma_{ij}} \delta \dot{\epsilon_{ij}} dV + \Delta t \int_{S_I} (\dot{T}_n \delta \dot{u_n} + \dot{T}_t \delta \dot{u_t}) dS = \Delta t \int_S \dot{T}_i \delta u_i dS, \tag{2}$$

where V denotes the volume of the unit cell having the surface S, S_I is the surface of the fiber-matrix interface, u_i is the displacement and T_i is the traction. The total strain is denoted by ϵ_{ij} and σ_{ij} is the Cauchy stress tensor. To avoid numerical problems during debonding, a combination of Rayleigh-Ritz method with the finite element procedure is implemented [2]. By this method, a sudden stress-drop of the overall average stress-strain response may be captured [1]. Furthermore, this procedure gives the possibility to control the stress applied to the cell while using displacement controlled symmetry boundary conditions. Finally, a parametric study is carried out to assess the influence of the geometrical parameters, fiber volume fraction, $V_f = \frac{\pi R^2}{2ab}$, and interfacial properties on the average stress-strain curve. In Fig. 2, results for purely elastic condition for case II are shown. In Fig. 2(a), a contour plot of the unit cell is depicted when loaded uniaxially in the x_2 direction. In Figs. 2(b) and 2(c), the effects of the fiber volume fraction and the critical cohesive zone separation are shown on the overall response, respectively. This extended unit cell study of composites focuses on the progressive fibermatrix debonding when one fiber experiences a neighboring fiber with a dissimilar interfacial strength.

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